

EVOLUTION OF PRE-MAIN SEQUENCE ACCRETION DISKS

Grant NAG5-9670

Annual Report #3

For the period 1 July 2002 through 30 June 2003

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April 2003

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, MD

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<p>The Smithsonian Astrophysical Observatory is a member of the Harvard-Smithsonian Center for Astrophysics</p>

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Introduction

The aim of this project is to develop a comprehensive global picture of the physical conditions in, and evolutionary timescales of, pre-main sequence accretion disks. The results of this work will help constrain the initial conditions for planet formation.

To this end we are developing much larger samples of 3-10 Myr-old stars to provide better empirical constraints on protoplanetary disk evolution; measuring disk accretion rates in these systems; and constructing detailed model disk structures consistent with observations to infer physical conditions such as grain growth in protoplanetary disks.

1. Past year

i. Cluster survey

We are continuing our observational program to identify star clusters with ages of 3-10 Myr which are sufficiently populous to provide good statistical information on disk properties as a function of stellar mass and age. We have identified two such clusters, Tr 37 and NGC 7160, which lie in the Cep OB2 association at a distance of approximately 900 pc.

We have recently completed a study of the massive and intermediate-mass stars in Tr 37 (Contreras et al. 2002). The photometry and spectroscopy help to refine the membership, reddening ($A_V \sim 1.5 \pm 0.5$), and distance modulus ($m - M = 9.7 \pm 0.2$) to this cluster. Only three new emission-line stars were found in our sample, resulting in a total of four stars in the cluster with emission lines and spectral type earlier than G. One of these emission-line stars, LkH α 349, is probably not a member of the central cluster, as it lies within a dark globule on the periphery of the H II region IC 1396. Three of the four emission line stars show near-infrared excesses characteristic of circumstellar disks. Thus, at an age of about 3 Myr, as estimated from the expansion age of molecular material around the cluster, emission-line phenomena driven by disk accretion are extremely rare through spectral types F (masses $\gtrsim 1.5M_\odot$).

Using CCD photometry from 4-shooter mosaic camera on the SAO 1.5m meter telescope on Mt. Hopkins, we identified candidate cluster members from their positions in the color-magnitude diagram, and then obtained followup spectroscopy for these candidates using the Hydra multifiber bench spectrograph on the WIYN telescope on Kitt Peak. Using H α emission and Li I absorption indicators, we were able to identify low-mass members in these clusters and confirm the ages discussed above. Figure 1 shows the latest color-magnitude diagram for Tr 37.

A remarkable and unexpected result is that we found a highly non-uniform distribution of low-mass stars in Tr 37, which seems to differ from that of the intermediate-mass stars

(Figure 2). The origin of this distribution is not understood. One possibility is that stars near the central O7 star have had their disks evaporated; thus, only weak-emission, non-accreting stars are in the cluster center, and such stars would be difficult for us to detect given the strong nebular $H\alpha$ emission. This does not explain, however, why the stars would be strongly concentrated to the west.

ii. Filaments and protostellar fragmentation in Taurus

In a recent paper (Hartmann 2002b), the remarkably filamentary spatial distribution of young stars in the Taurus molecular cloud has significant implications for understanding low-mass star formation in relatively quiescent conditions. The large-scale organization and regular spacing of the filaments suggests the presence of important, if not dominant, large-scale turbulent motions, perhaps channeled in part by magnetic fields, which would be consistent with turbulent driving on large scales by flows which produced the cloud. The small spatial dispersion of stars from gaseous filaments indicates that the low-mass stars are generally born with small velocity dispersions relative to their natal gas, of order the sound speed or less. The spatial distribution of the stars exhibits a mean separation of about 0.25 pc, comparable to the estimated Jeans length in the densest gaseous filaments. The protostellar cores are generally aligned with the filaments, suggesting that they are produced by gravitational fragmentation, resulting in initially quasi-prolate cores. Given the absence of massive stars which could strongly dominate cloud dynamics, Taurus provides important tests of theories of dispersed low-mass star formation and numerical simulations of molecular cloud structure and evolution.

iii. Disk accretion

In a recently accepted paper (Muzerolle *et al.* 2003a), we studied disk accretion in very low mass stars. Using limits on continuum veiling and modelling $H\alpha$ line emission which arises in magnetospheric accretion columns, we showed that very low mass T Tauri stars accrete at very low rates, $10^{12} < \dot{M} < 10^{19} M_{\oplus} \text{ yr}^{-1}$, with a clear dependence on mass.

The mass dependence of accretion was more explicitly examined in a submitted paper (Muzerolle *et al.* 2003b) in which we added results from intermediate-mass stars. Over the entire range from $0.04 - 4 M_{\oplus}$, we find increasing mass accretion rates with increasing mass. The overall trend is roughly $\dot{M} \propto M^{2.3}$, with a large scatter at each mass. The physical origin of this relation is not clear; standard viscous accretion disk models predict some correlation but not as steep a relation as we find. We suggest that X-ray ionization of the disk may provide an additional mass-dependent effect on the angular momentum transport needed for accretion; this possibility needs to be explored with further theoretical and observational work.

2. Next year

We have requested further observing time with Hydra on the WIYN telescope for fall 2003 to help identify further members of NGC 7160 and Tr 37, with special emphasis on subtracting nebular emission.

This program has been delayed because we were expecting to use the multiobject Hectospec and Hectochelle spectrographs on the converted 6.5 MMT telescope. These powerful instruments, when in operation, should provide a major advance over the WIYN Hydra observations, enabling us to complete our project with only two to three nights of observing time. Unfortunately, progress in completing the wide-field capability of the telescope has been delayed. However, the appropriate secondary has been installed and tested successfully, the spectrographs are in place, and the fiber positioner is scheduled to be installed in summer 2003. Thus we hope to make observations this fall on our clusters and complete the membership identification. The photometric and spectroscopic reductions are being performed by CfA predoctoral fellow Aurora Sicilia Aguilar as part of her thesis research, which should be completed by the end of summer 2004.

NGC 7160 and Trumpler 37 are targets in the PI's guaranteed time observing program with SIRTf to study disk evolution. The launch date for SIRTf is now September 2003. Thus SIRTf measurements of infrared disk emission in these clusters should become available near the end of the reporting period, and we will reducing and analyze these data in the coming year.

Papers supported by this grant during last year

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- Osorio, M., D'Alessio, P., Muzerolle, J., Calvet, N., & Hartmann, L. 2003, ApJ, 586, 1148
- Reipurth, B., Hartmann, L., Kenyon, S.J., Smette, A., & Bouchet P. 2002, AJ, 124, 2194

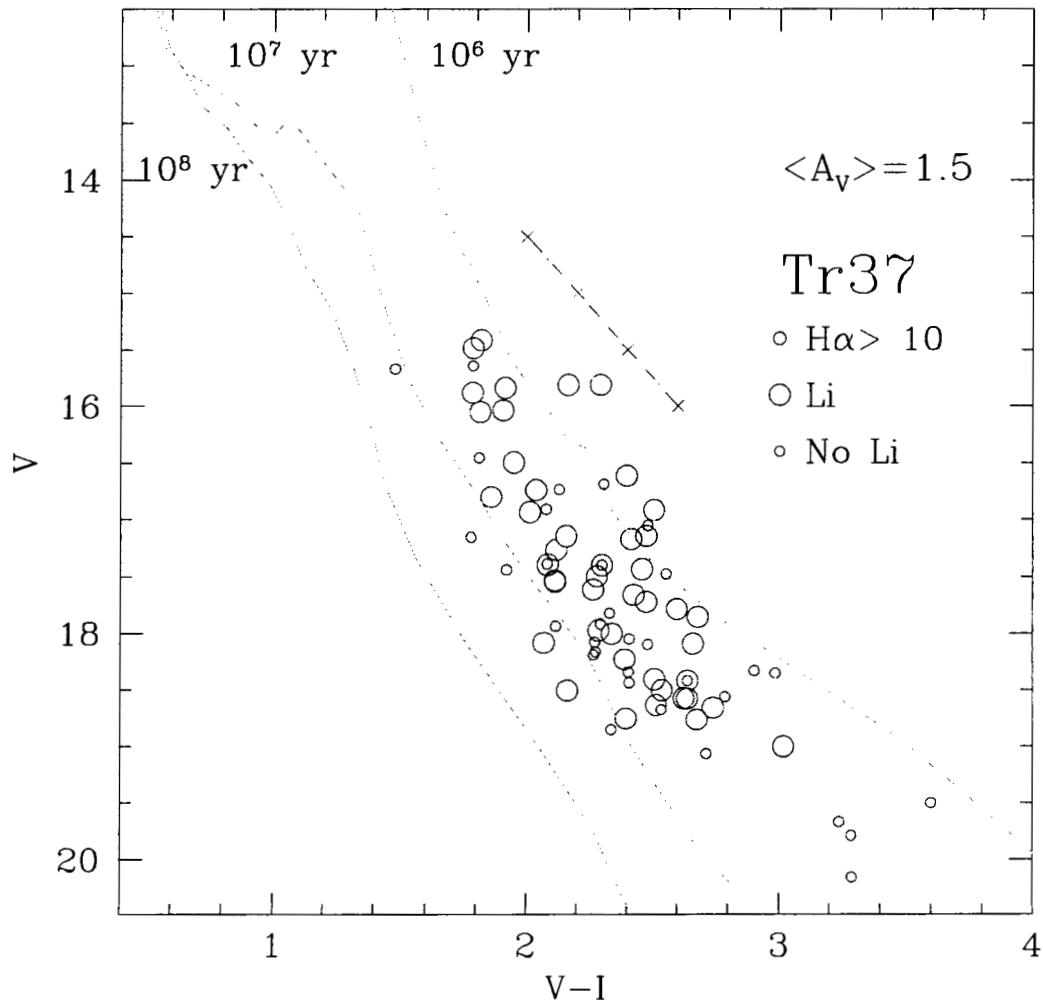


Figure 1: Optical color-magnitude diagram of identified members in Tr 37, roughly consistent with the ~ 3 Myr age for the cluster estimated from the dynamical age of associated gas and the upper main sequence turnoff. Large circles indicate stars with detectable Li 6707 Å absorption. Small circles stand for cases of uncertain Li detection. Shaded symbols are assigned to stars showing strong $H\alpha$ emission ($EQW > 10$ Å).

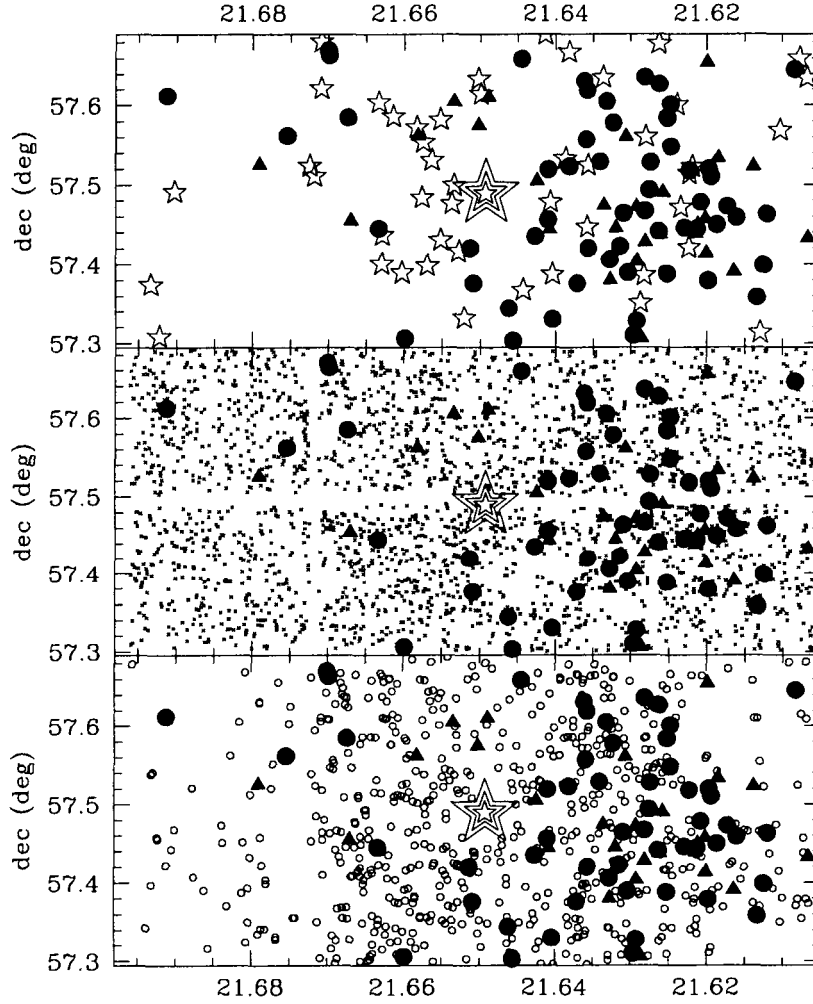


Figure 2: Spatial distribution of stars in Tr 37. Large star: O6 central star HD206267. Small stars: B and A cluster members. Black large circles: CTTS. Black large triangles: WTTS. Upper figure: Distribution of cluster TTS versus high and intermediate mass stars. Middle figure: Distribution of candidates (small crosses) versus TTS. Lower figure: Distribution of observed targets (small open circles) versus TTS. The asymmetry of TTS vs. higher mass members is clear from the upper panel. The lower panel shows the non-uniform sampling along the East-West direction. Targets near the O star suffer from strong nebular $H\alpha$ contamination, making it difficult to find weak emission members.